



The International Association of Foundation Drilling

STANDARD DRILLED SHAFT ANOMALY MITIGATION PLAN

**ADSC Drilled Shaft Committee
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INTRODUCTION

As Drilled Shaft Subcontractors, one of our main goals in the execution of our work is to install a quality product. The owner will typically include a Non-Destructive Testing (NDT) requirement in the contract specifications in order to verify the contractors' installation techniques. Typical NDT includes, but is not limited to: Gamma-Gamma Logging (GGL), Crosshole-Sonic Logging, (CSL), and Thermal Integrity Profiling (TIP). GGL is typically performed in 2" pvc pipes that are tied to the reinforcing cage prior to placement into the Shaft. CSL is typically performed in 2" steel pipe (although pvc can be used) that are tied to the reinforcing cage prior to placement into the Shaft. TIP can be performed in pipes that are tied to the reinforcing cage prior to placement into the Shaft or a wire with thermal couples is attached at equal intervals around the reinforcing cage prior to placement into the Shaft.

No matter how diligent our crews are in drilling, cleaning and placing concrete; occasionally an anomaly (defined as: a deviation from the norm, an irregularity) will be discovered during the Non-destructive testing (typically performed by the owner / public agency). When an anomaly is discovered, the engineer of record is requested to determine if the anomaly will require a repair or whether it is acceptable as-is.

Most of the time, the work performed by the Drilled Shaft Contractor is on the Critical Path of the project schedule. When an anomaly is required to be repaired, the time it takes to put a plan together and get it approved can greatly affect the schedule.

The intent of this "Standard Drilled Shaft Anomaly Mitigation Plan" is to have a pre-approved plan that can be used for several types of "typical" anomalies prior to the start of work so that any repairs can be performed quickly and with little impact to the project schedule.

The following recommendations / plans are based on the "ADSC Standard Mitigation Plan" that was written by the ADSC West Coast Chapter and reviewed and approved by Caltrans' (California Department of Transportation) Foundation Testing Branch and implemented for use in 2007. They have been reviewed and edited by the ADSC-IAFD Drilled Shaft Committee to be used in conjunction with Non-Destructive Testing Methods listed above.

Since NDT can be performed in either PVC or Steel Pipes, access to an anomaly can be gained by the high-pressure removal of the pvc pipe by water jetting or by drilling / coring down to the anomalous zone. When steel pipes are used, it is recommended to

install pvc caps rather than steel caps on the bottom of the pipes to allow for easy removal should grouting at the tip of the pile be required.

This Standard Drilled Shaft Anomaly Mitigation Plan consists of two Plans: Standard Mitigation Plan "A" which contains typical procedures for a "basic repair" of anomalies, and Standard Mitigation Plan "B" which contains typical procedures for mitigation by replacement and/or permeation grouting methods.

To address the wide range of anomalies that may be candidates for grouting repair, Standard Mitigation Plan "B" is broad in scope and contains provisions that will not be applicable to all anomalies. Although the generic nature of the plan may lead to some inefficiency in mitigation operations, the intention of the standard plan is to expedite the acceptance of typical mitigation plans by providing a template for formal submission to the owner. The submittal of an anomaly mitigation plan can be made job specific by the attachment of a cover letter which addresses the specific site conditions and contract requirements.

These standard mitigation plans do not address specific anomalies. Thus, the plans do not contain some of the components of a typical mitigation plan, such as a description of the subject anomalies and a review of project documents.

These standard plans do not purport to address safety concerns associated with their use. It is the responsibility of the contractor to establish appropriate health and safety practices and to determine the applicability of regulatory limitations prior to performing the work.

STANDARD MITIGATION PLAN “A” - BASIC REPAIR

OVERVIEW OF MITIGATION PLAN “A”

Standard mitigation plan “A” describes a typical procedure for basic repair. Basic repair involves the mechanical removal and replacement of concrete within an anomalous zone. Basic repair is typically performed by hand; thus, the anomalies to be repaired must be accessible, or the anomalies must be accessed by excavation. Basic repair performed near the top of a pile is also known as “simple” repair. Restoration of earthen materials may be required if the anomalies to be repaired are not immediately accessible.

MITIGATION PLAN “A”

A basic repair involves mechanical removal and replacement of concrete from anomalies accessed from the ground surface or by excavation. Mechanical removal is performed using a chipping gun or similar means under the observation and direction of the inspector / engineer.

A. Excavation

1. Excavate alongside the drilled shaft in the vicinity of the designated inspection tube(s) to a depth of one foot below the identified anomaly to provide access. Shoring plans, confined space plans, and provisions for replacement of earthen materials disturbed by excavation shall be submitted as appropriate.

B. Removal of Deleterious Material

1. After excavation and exposure of the anomaly, all visually deleterious or questionable material will be removed. Mechanical removal will “chase” all inclusions or compromised concrete until competent concrete is encountered.
2. If the surface of the Drilled shaft shows apparently competent concrete, a small section in the center of the identified anomaly will be chipped a minimum depth of one inch to demonstrate that the surface manifestation is consistent with concrete below the pile surface.

C. Inconclusive Results

1. If visual inspection is inconclusive, a 2 or 3-inch diameter core sample can be obtained from the anomalous zone for additional visual inspection and/or strength testing. The core should extend 6 to 12-inches beyond the anomalous zone or as approved by the owner. Strength testing shall be performed in accordance with standard testing procedures.
2. If visual inspection or the results of compressive strength testing indicate that the concrete is not acceptable, the unacceptable concrete shall be mechanically removed to the extent determined by the inspector.
3. If the results indicate that the concrete is acceptable as-is, the contractor should be compensated for the investigative work performed.

D. Verification of Results by Engineer

1. After the Contractor has removed all material that is visibly compromised or questionable, the Engineer will visually and physically inspect the effectiveness of the removal operation. If the concrete is deemed acceptable, the removal will be terminated and approved. If additional questionable material is identified, the Contractor shall remove this material and request that the Engineer re-inspect.

E. Replacement

1. After removal of unacceptable concrete and questionable material, forms shall be constructed as necessary, and the specified concrete mix shall be placed in the repair area, or alternatively, at the acceptance of the engineer/owner, the area can be poured back with the follow-on concrete work (column pour or footing pour)
2. After the concrete has cured, forms shall be removed.

F. Restoration of Earthen Materials

1. Earthen materials shall be replaced as approved by the owner. Where not otherwise designated, earthen materials shall be replaced using the excavated soil and compacted to a relative density that approximates the undisturbed, in-situ density of adjacent earthen materials. Two-sack sand slurry may be used if the Engineer of Record indicates that this will not adversely affect the lateral stiffness of the pile.

G. Reporting

1. Upon completion of the mitigation procedure, a mitigation report shall be submitted stating what repair work was performed and whether the repair work conformed with the mitigation plan. Any deviations from the mitigation plan must be stated in the report.

STANDARD MITIGATION PLAN “B” - GROUTING REPAIR

OVERVIEW OF MITIGATION PLAN “B”

Standard mitigation plan “B” describes typical procedures for grouting repair. Pile design data, construction details, subsurface conditions, and the results of conformance testing are considered in the development of a grouting mitigation plan. The formation conditions and extent of communication often cannot be completely characterized by the results of water flow testing and thus may be largely unknown at the start of grouting. Thus, provisions for both replacement grouting and permeation grouting are presented in standard mitigation plan “B”.

If grouting is determined to be a potentially effective method of repair, anomaly mitigation may include several of the following steps:

- Coring (when Steel Pipes are used)
- High-pressure cutting of inspection tubes (when PVC Pipe is used)
- High-pressure washing;
- Water flow testing;
- Flushing (high-volume, low-pressure washing);
- Down-hole camera observation;
- Grouting: replacement of permeation:
- Conformance testing,(if deemed necessary) and;
- Final documentation.

The mitigation procedure should be performed by a contractor and crew who are experienced in grouting repair. The mitigation contractor and/or the engineer should keep records during pressure washing, pressure testing and grouting using an approved form / format.

Pressure washing and grouting are typically performed by accessing the anomaly through a cored hole adjacent to a steel inspection tube or through the existing PVC inspection tubes.

Water flow testing is performed after pressure washing and often provides additional information regarding the appropriate mitigation method. Permeation grouting should be performed only if communication with the surrounding geomaterials is evidenced by sufficient flow during water flow testing. If communication is not evident, alternate methods of repair such as replacement grouting may be applicable. Video of the anomaly after pressure washing may also be useful for characterizing the nature of the anomaly and determining the mitigation method.

The grouting procedure is generally intended to increase compressive strength and/or frictional resistance and to reduce the chance of steel corrosion. Grouting generally does not adversely affect geotechnical design criteria. Restoration of earthen materials is typically not required as a result of grouting. Grout and wash water may daylight during repair of anomalies located at relatively shallow depth. Care should be taken so that the surrounding surface soil does not heave. Reduced grout pressures may need to be employed if ground heave is observed.

After completion of the repair procedures, post-mitigation non-destructive testing may be required. Post-mitigation non-destructive testing from the original inspection tubes can be problematic because of the relatively low density of the grout, as well as the difficulty in repairing the anomaly immediately around the tube while preserving the tube's integrity. Coring may be used in some circumstances to recover samples of the grouted materials for visual inspection and strength testing. Typically, the success of grouting mitigation is addressed qualitatively based on observation of the mitigation procedure and review of information such as pressure test results and grout take. The mitigation is typically observed by an engineer, who prepares a mitigation report summarizing the mitigation procedure.

Coring or High-Pressure Cutting of PVC Inspection Tubes

When steel inspection tubes are used (Typically for CSL Testing), a cored hole extending from the top of the pile down to and 6 to 12-inches beyond the anomaly, will be used. Care should be taken when coring in order to use the core to assess the quality or compressive strength of concrete. Typically a double wall core barrel system utilizing a split tube type inner barrel is required. Cores should be logged and labeled for latter use in assessing the repair required. Rotary-drilled holes may be appropriate to provide access for coring.

If additional ports are required beyond an initial cored hole, air-rotary equipment is typically employed. The drilled holes should be at least two inches in diameter. Care should be taken to avoid reinforcing steel. Due to potential difficulties associated with grouting the drilled holes below the anomalous zone, and if the vertical extent of the anomaly is easily detected during trial drilling, drilling typically extends only to the bottom of the anomaly.

When PVC inspection tubes are used, the tubes can be removed from the anomalous zone using a high-pressure washing procedure. The tubes are cut by a stream of high-pressure water, directed laterally against the side of the hole, and rotated as it is slowly withdrawn. Pressure at the pump should be adjusted to account for pressure losses in the line. Excessive pressure loss in the line may

result in pressures at the tip that are insufficient to remove the PVC inspection tubes.

Good results have been obtained using water pressure of 10,000 to 15,000 psi at 10 to 15 gpm. Higher pressure may cut the concrete around the tube, and lower flow rates may be less efficient for removal of the plastic. However, satisfactory results have been achieved with pressure between 7,000 and 30,000 psi. Inspection tube removal should extend from 6 to 12-inches below to 6 to 12-inches above the anomaly. Inspection tubes need not be fully removed at all locations but visual inspection should be performed to approve cleanliness of the area prior to grouting operation.

High-Pressure Washing

The anomaly is pressure washed with high-pressure water concurrently with the tube removal process. The water jet used to cut the tubes also acts on the defective concrete as the plastic is removed. As a general rule, water pressure of 10,000 to 12,000 psi will not affect sound concrete, while higher pressure may remove sound concrete.

A high-pressure submerged jet may be effective at removing segregated concrete, honeycomb concrete and/or inclusions in the concrete. In addition, the jet may break through the concrete to the soil or rock outside of the drilled shaft. The nature of the material cut by the jet can often be determined by observation of the color and grain size of the cuttings returned to the surface. Concrete materials generally run grey to milky with few large pieces, while soil has a wide range of color and heavier suspended solids.

The pressure washing procedure should be monitored to reduce the chance of disturbance of soil adjacent to the shaft while attempting to remove deleterious material from the anomaly. Solids content in the wash return water should be monitored by periodically straining solids out of the effluent. If significant solids content is observed in the return water, the washing may be causing excessive disturbance of the surrounding formation. If native material is not observed in the return water, washing may be continued until the solids content of the return water is deemed insignificant. The contractor should keep a log of communication between holes, water color, type of solids, and estimated solids content.

Water Flow Testing

Water flow testing is performed for each inspection tube. Initially, all other ports are open. Water should be injected through the grout plant, and signs of communication to other holes or to the ground surface should be recorded. The contractor should record the pressure, injection rate and communicating tubes.

After all communicating ports are closed, water flow testing shall be continued to determine whether there is significant communication with the formation. Perform a qualitative evaluation of the water flow test based on injection rate and pressure. A water injection rate into the inspection tube of less than 2 gpm at a pressure of 10 to 20 psi (in addition to the existing hydrostatic pressure in the inspection tube) may be considered insufficient communication for permeation grouting. In the case of insufficient communication, replacement grouting should be considered.

A falling head water flow test may also be used to determine whether there is adequate communication to perform permeation grouting. The criterion for adequate communication is typically more stringent for the falling head test than for the water flow testing described above.

If the flow of groundwater into the inspection tubes is not rapid, the inspection tubes are typically cleared by air injection after water flow testing and prior to down-hole camera observation or grouting.

Flushing

Flushing (high-volume, low-pressure washing) should be performed if there is significant communication between inspection tubes. The purpose of flushing is to remove loose material after pressure washing and prior to grouting or down-hole camera observation. Flushing may involve pumping large amounts of water into an inspection tube and allowing it to return from another or washing material up around a tremmie tube inserted into a single inspection tube. Air, water or alternating injections of air and water may be used for flushing. Solids content in the wash return water should be monitored by periodically straining solids out of the effluent.

Down-Hole Camera Observation

Down-hole camera observation may be performed to verify that the PVC inspection tubes and/or deleterious materials were adequately removed from the anomalous zone. Dry conditions are typically preferable for camera observation. If camera observation is to be performed under water, flushing may be necessary to remove suspended materials from the water within the inspection tubes and scoured anomaly area.

Replacement Grouting

Replacement grouting is intended to fill voids with a relatively low-slump, mortar-type mix. Contaminated concrete and other deleterious material must be removed from an anomaly. This is typically accomplished by high-pressure washing as described earlier, prior to replacement grouting. Flushing may be employed if large

voids are present that allow communication between ports. Grout typically consists of Type I/II or II/V cement mixed at the ratio of one 94-lb sack of cement per 4.5 to 5- gallons of water and is pumped at a pressure of up to 150 psi. Drilling of additional holes into the anomalous zone may be required to promote communication and to reduce the chance of air entrapment within isolated portions of the anomalous zone.

Prior to replacement grouting, the anomaly is cleared of water by injecting compressed air through the inspection tube at the base of the anomaly. Water and air typically return through an adjacent tube, if communication exists, or through the annular space in the tube around the air line.

Permeation Grouting

Typical permeation grouting repair involves high-pressure injection of a water-based, high-slump slurry of cement grout into the pore volume of soil, or contaminated concrete or sediment within a drilled shaft. Permeation grouting results in little disturbance of the material and is accompanied by displacement of pore water. Grain size for microfine cement grout typically ranges from 4 to 8 microns, whereas the grain size for typical Portland cement ranges from 20 to 50 microns. Permeation of the matrix decreases as voids are filled with cement solids.

Permeation grouting is generally effective when the pore aperture or fracture width in soil or rock is approximately five or more times as large as the effective grain size of the grout material. This is often expressed as the groutability ratio ($D_{15,SOIL} / D_{85,GROUT} \geq 5$). However, there are enough exceptions to this rule that a grouting specialist should be consulted before starting a large or costly grouting program. The grouting contractor should typically assess and confirm the feasibility of permeation grouting based on the results of pressure testing.

In most permeation grouting scenarios, there is a pathway for the pore water to escape from the grout injection zone. In the case of grouting a defect in a drilled shaft, there may not be a pathway, or the path may be constricted. This is an inherent limitation on the ability to successfully permeate a concrete defect. Anomaly mitigation by permeation grouting is typically intended to address “soft tip” anomalies, to increase frictional side resistance, and decrease corrosion, rather than to fill all potentially disconnected voids within an anomaly.

In a typical permeation grouting scenario, the grout flow is laminar and displaces most of the trapped pore fluid. If the grout is stable, it cures with less than a 10% separation of solids from the water fraction of the grout. Unstable grout “bleeds”, leaving a layer of solids in the bottom of the pores with a layer of mix water above.

Similarly, a macroscopic void may only be partially filled with solids if unstable grout mixes are used.

The cement solids used for grouting have a specific gravity in the range of 2.75 to 3.17 for ordinary Portland cement. Depending on the water/cement ratio needed to achieve the required viscosity of the grout, density of the grout mix varies but is usually much less than the structural mix used for drilled shaft construction.

The relatively low density of microfine cement may not meet GGL density requirements. When the low-density material in the anomalous zones is permeated or replaced by the grout during the mitigation procedure, GGL post-mitigation non-destructive testing may not result in densities that meet the standard acceptance criterion, which is typically defined as the average surrounding concrete density minus three standard deviations.

Conformance Testing

Quantification of the success of permeation or replacement grouting may require conformance testing. Testing may include Cross-hole Sonic Logging (CSL), Gamma-Gamma Logging (GGL), coring, or excavation. CSL and GGL confirmation testing is often inconclusive due, in part, to the difficulty of washing and grouting adjacent to the inspection tubes while preserving their integrity. The relatively low density of the grout solids also contributes to the difficulty in interpretation of test results. For these reasons, and due to the high cost of invasive confirmation testing procedures, the mitigation procedure is often evaluated qualitatively based on the results of pressure testing, communication and grout take.

Mitigation Report

Upon completion of the mitigation procedure, a post-mitigation report is to be submitted to the Engineer stating what repair work was performed and whether the repair work conformed with the mitigation plan. Any deviations from the mitigation plan must be stated in the report. The Engineer should review the report and determines whether the mitigation efforts were successful.

MITIGATION PLAN "B"

A.1. Coring

1. 3-inch diameter minimum, double wall core barrel system utilizing a split tube type inner barrel is used. This will give a 2 to 2-1/2-inch core sample that can be used for compressive testing.
2. Cored holes should be located as close to the access tube as possible but no further away than 6". Cored holes need to plumb to ensure that they do not cut into the adjacent access tube or into any of the reinforcing steel.
3. At a minimum, cores should extend 6 to 12-inches below the anomalous zone.
4. Cores should be logged and labeled for latter use in assessing the repair required and for compressive strength testing if required.
5. Rotary-drilled holes, drilled to within 24-inches of the anomalous zone, may be appropriate to provide access for coring.

A.2. PVC Inspection Tube Removal

1. The PVC inspection tube shall be cut with high pressure water for the entire elevation range of the anomaly, extending from two feet below the anomaly to two feet above the anomaly. Water jetting shall begin from the lowest anomalous region and proceed upward. Only one anomaly shall be washed and grouted at a time, except where approved in writing by the Engineer.
2. The Contractor shall make provisions to ensure that the required cutting pressure is achieved at the anomaly depth and that the PVC tube is predominately removed at the repair location (complete removal is not necessary). Water pressures typically range from 9,000 to 15,000 psi at a rate of 10 to 15 gpm. Several hundred psi may be lost in the line as a result of pump and line configuration.

B. High-Pressure Washing

1. The anomaly shall be pressure washed with the high pressure water directed laterally against the side of the hole and rotated as it is slowly withdrawn. Water pressure shall be approximately 10,000 psi at 10 to 15 gpm, or as required to remove the deleterious material. Washing shall begin from the lowest anomalous region and proceed upward.
2. Washing will continue until no further solids are observed emanating from the inspection tube and the return flush water is clear, except in the case of erosion of native material, as noted in paragraph 5 below.
3. The Contractor shall monitor the solids content in the wash return water by periodically straining solids out of the effluent.
4. The Contractor shall keep a log of unanticipated communication between holes, water color, type of solids, and estimated solids content.
5. The pressure washing procedure shall be monitored to reduce the chance of disturbance of the formation around the pile while attempting to remove loose sediment and contaminated concrete. Washing shall be discontinued if evidence of significant erosion of native material is observed.

C. Flushing

1. Flushing (high-volume, low-pressure washing) shall be performed if there is significant communication between cored holes or inspection tubes. The purpose of flushing is to remove loose material after pressure washing and prior to grouting or down-hole camera observation.
2. Water shall be pumped into a cored hole or inspection tube and be allowed to return from another hole/tube or around a tremmie tube inserted into a single inspection tube. Air, water or alternating injections of air and water may be used for flushing.
3. Flushing will continue until no significant solids are observed emanating from the cored hole or inspection tube and the return flush water is clear, except in the case of erosion of native material, as noted in paragraph 6 below.

4. The Contractor shall monitor the solids content in the wash return water by periodically straining solids out of the effluent.
5. The Contractor shall keep a log of unanticipated communication between holes, water color, type of solids, and estimated solids content.
6. The flushing procedure shall be monitored to reduce the chance of disturbance of the formation around the pile while attempting to remove loose sediment and contaminated concrete. Flushing shall be discontinued if evidence of significant erosion of native material is observed.

D. Water Flow Test

1. A packer shall be seated in the tube below the top of the concrete, or the inspection tube shall be sealed by other means, as deemed appropriate by the Contractor. The Contractor shall be solely responsible for any health and safety requirements.
2. Valves on all ports shall be open.
3. Water shall be injected through the grout port.
4. The Contractor shall record pressure, injection rate, signs of communication to other ports, signs of communication to the ground surface, amount of water used, color of return water, and time.
5. After all communicating ports are closed, the water flow testing shall be continued to determine whether there is significant permittivity (flow into the formation). A water injection rate into the inspection tube of less than 1 gpm at a pressure of 10 to 20 psi (in addition to the existing hydrostatic pressure in the inspection tube) is typically considered insufficient permittivity for permeation grouting. In the case of insufficient permittivity, replacement grouting is to be utilized, unless other factors provide compelling reasons not to utilize replacement grouting.
6. If permeation grouting is to be performed, the water injection rate will be used to help determine an appropriate water:cement ratio for the starting grout mix. The starting grout mix will be determined based on the attached Chart 1. For example, a take of 20 gpm at 10 to 20 psi

indicates that a thin starting mix (such as mix #1 presented in the attached Grout Mix Table) is preferred. Take of 10 gpm at 10 to 20 psi indicates that a starting mix such as No. 2 or 3 is preferred. Take lower than 10 gpm indicates that lower water:cement ratios are appropriate for the starting mix, as suggested by Chart 1 and determined in the field .

7. If the Contractor suspects insignificant water flow and plans to mitigate by replacement grouting, the falling head test, as described below, may be used as an alternative to the water flow test procedure described in this section. The purpose of the falling head test is to verify that flow is insignificant prior to performing replacement grouting. If the results of the falling head test indicate that flow into the surrounding formation exists, the water flow test described in this section will be performed.

E. Falling Head Test: To be used in lieu of the “Water Flow Test” when the contractor suspects insignificant water flow into the formation.

1. If groundwater is within 25 feet (7.6 m) of the top of the inspection tube, the tube shall be extended a minimum of 25 feet above the groundwater table.
2. The inspection tubes shall be filled to the top with water.
3. If communication exists between tubes, the falling head test shall be performed concurrently in communicating tubes.
4. Flow into the formation will be evidenced by a drop in water level inside the inspection tube. If flow into the formation is demonstrated, a water flow test is to be performed. Replacement grouting is to be performed if flow into the formation is not evident.

F. Down-Hole Camera Observation (Optional)

1. Down-hole camera observation shall be performed, if required, after high-pressure washing and flushing. The purpose of down-hole camera observation is to verify that the PVC inspection tubes are predominately removed from the anomalous zone, to verify that deleterious materials have been adequately removed, and to provide additional information regarding the character and extent of the anomaly.

2. Dry conditions are typically preferable for camera observation. If the flow of groundwater into the cored hole or inspection tubes is not rapid, i.e., 2 to 3 gpm at 10 to 20 psi, the core or inspection tubes shall be cleared by air injection after water flow testing and prior to down-hole camera observation or replacement grouting. Camera observation under water may be performed if visibility is acceptable. If camera observation is to be performed under water, flushing will be performed to remove suspended materials from the water within the inspection tubes and scoured anomaly area if visibility is poor.

G. Permeation Grouting

The permeation grouting procedures presented below are intended to serve as the standard procedures for grouting. On occasion, it may be necessary to modify the procedures contained herein in response to field conditions to achieve the desired result. Any alteration of the standard plan should be clearly identified in the submitted post-mitigation report.

- a. *Evaluate water pressure and rate of take based on water flow test results, as discussed above. If the water flow test indicates that permeation grouting should not be utilized, do not proceed.*
 - b. *Permeation grouting requires that sufficient confining pressure be present to conduct grouting operations without grout returning to the surface. Permeation grouting should not be selected for pile mitigation less than 10 feet from the ground (or working) surface.*
 - c. *The intent of grouting for drilled shafts is to address the structural, geotechnical and corrosion concerns identified for that foundation element. To that end, grouting purposes to promote the maximum rate of solids injection, as opposed to the maximum rate of grout injection.*
 - d. *The Contractor shall be solely responsible for any and all health and safety requirements.*
1. Superfine (Nittetsu) cement shall be used for permeation grouting. Grout mix ratios and mix designations are presented in Table 1.
 - a. The ratios shown in the attached Table 1 are based on Nittetsu Superfine cement packaged in 22 kg (48.4 lb) bags and having a

- specific gravity of 2.75. A batch of permeation grout is typically 33 gallons.
- b. Thin grout mixes (such as mixes #1 through #6) are not appropriate for structural mitigation if injected into a void, as they are unstable and will generally not achieve the required design strength.
 - c. Due to the small grain size of Nittetsu Superfine cement, the mix becomes thixotropic at a water:cement (W:C) ratio of 0.8:1. The superplasticizer also acts as a retarder. Use of superplasticizer will be determined by the grouting Contractor, as required for favorable flow characteristics and to reduce the chance of grouting equipment damage. The Contractor is solely responsible for performing the grouting procedure in such a manner that equipment does not become plugged or otherwise damaged. Use of superplasticizer shall be in accordance with the microfine cement manufacturer's recommendations.
 - d. The actual volume of the voids is not known, and grout solids are likely to enter the surrounding formation. The Contractor shall secure an adequate supply of cement and water for the repairs. The compressive strength of materials permeated with microfine cement solids depends not only on the strength of the grout, but also on the strength of the solid matrix into which the grout is injected. Strength generation is generally slow due to the superplasticizer. Actual strengths will depend upon grout solids permeation and matrix characteristics.
- 2.. The starting grout mix will be determined by the grouting contractor based on the results of water flow testing. The starting grout mix will be in accordance with Table 1.
3. Grout shall initially be placed by tremie until it returns from the top of the injection port at a consistency similar to the injected grout. If starting with mix #1 or #2, significant communication and bleed off is anticipated, initial tremie placement is not necessary.
4. Inflate packers to seal tube. Where multiple cores / tubes are being grouted in the same process, all tubes must be grouted simultaneously by means of a common manifold. Alternate means that accomplish the same intent may be utilized where approved by the Engineer.

5. Batches of grout shall be injected under pressure, beginning with the starting grout mix.
6. At the completion of each batch of grout, the Contractor shall evaluate the grout take and pressure to determine the thickness of the next batch of grout to be injected. The grout mix will be increased as pressure increases in general accordance with Table 1. If the starting mix is thicker than the mix indicated by Table 1, continue to use the starting mix.
 - a. The grout mix number is increased as the grouting pressure increases, to reduce the chance of premature refusal during a void filling application and to progressively thicken mix to structural mixes as pores within the grouted material become filled.
7. Inject next batch of grout and repeat Step 6 until refusal is reached. For refusal, see Step 11.
8. If the formation does not appear to be plugging (If the pressure does not increase or flow rate decrease after injection under pressure of three full batches), the contractor may elect to thicken the grout by one mix number.
 - a. If mix #7 or #8 does not plug the formation quickly, an ordinary Portland cement grout may be used. The replacement-type grout mix shall consist of Type I/II or II/V Portland cement mixed at the ratio of one 94-pound sack of cement per 4.5 to 5- gallons of water.
 - b. If plugging does not seem to be occurring with Mix #7, Mix #8 or Portland cement grout, the contractor may shut off the pump for intervals of 2 to 10 minutes to assist grouting process.
9. If grout returns to the surface at any time, note the location and estimate the volume of grout seepage. Also estimate the thickness of the return grout. If the amount of grout return approximates the injection rate, shut off the pump for intervals of 2 to 5 minutes. Use shorter intervals initially or if using thick mixes. In the case of immediate, direct communication, attempt to plug the leak with a half batch of mix #7 followed by a half batch of mix #8.
 - a. If grout returns to the surface and interruptions in grouting do not control the leak, the contractor may thicken the grout to the

thickest mix possible and discontinue grouting when the thick grout reaches the surface. Identify this condition in the post-mitigation report.

10. The contractor shall consider known difficulties associated with thick mixes and plan accordingly.
 - a. When using thicker mixes such as #7 or #8, check the pressure frequently and be prepared to dilute the mix if signs of plugging in the hoses or fittings are noted (plugging is common with this mix). If the mix is diluted to address plugging of the equipment, do not inject the thinned mix into the pile.
 - b. When pumping mix #8, look for signs of hydro-fracturing and test for refusal frequently. (Mix #8 has a very high viscosity and will permeate only a few inches in most geomaterials.)
 - c. Mix #8 is often mixed in half-batches, especially for small grouting operations.
11. Refusal is defined as zero take at 150 psi. Grouting pressures shall be held for five minutes prior to release.
 - a. Refusal must be achieved with a sufficient quantity of structural grout mix (#7 or #8) for the grouting operation to be considered complete. If refusal is achieved during permeation grouting prior to injection of sufficient quantity of a structural grout mix, mix #8 will be tremied to the bottom of the anomaly location to completely displace thinner mixes.
 - i. "Sufficient Quantity" is considered to be greater than or equal to the estimated volume of the cavity developed by high-pressure washing, plus the volume of the tube/grouting port, plus the volume contained in the hoses above the anomaly to the grouting batching plant.
 - ii. Filling of the anomalous zone by tremie will be confirmed by consistent return of mix #8 at the top of the tube.
 - iii. Upon filling, the grout is to be pressurized to approximately 150 psi and held at that pressure for a minimum of five minutes.
 - iv. A sudden pressure drop at high pressures may be a sign that hydro-fracture of the formation has occurred during refusal. Indications of hydro-fracture are to be identified in the post-mitigation report.

12. All Equipment utilized by the Contractor shall be used according to manufacturer's recommendations in a safe manner that will result in the desired finished product.
 - a. The grout mixing and pumping unit shall be a colloidal mixer with a progressive cavity injection pump.
 - b. Pressure gauges shall be bourdon tubes with 4% accuracy. Gauge protectors shall be used and the gauges shall be replaced on a three- to four-shift cycle. The pressure range of the gauge shall be selected to allow for the anticipated grout pressure to fall in the middle third of the pressure range.

H. Replacement Grouting

1. The cored hole or inspection tube should be completely cleared of water. Extra care is required to assure all water is removed, as residual water will block the grout from completely filling the cavity. Begin tremmie placement in all tubes associated with the anomaly as soon as the water is cleared.
2. The anomaly and cored hole or inspection tube shall be filled with grout by tremmie from the bottom of the voided inspection tube. The tremmie shall be maintained below the level of the grout during placement. The tremmie shall be extracted when the inspection tube is completely filled with grout.
3. After the cored hole or inspection tube is completely filled with grout, the grout shall be pressurized through a port installed in the inspection tube to a minimum of 150 psi and held at that pressure for a minimum of five minutes. The Contractor shall be solely responsible for health and safety.
4. Grout shall consist of Type II cement mixed at the ratio of one sack of cement per five gallons of water. Using a 94-pound sack of cement, the water:cement ratio would be approximately 0.44. The Contractor shall verify that the grout strength corresponds to the required design strength.
5. The Contractor shall have an adequate supply of cement and water for the repairs.

I. Reporting

1. Upon completion of the mitigation procedure, a mitigation report shall be submitted to the Engineer stating what repair work was performed and whether the repair work conformed with the mitigation plan. Any deviations from the mitigation plan shall be stated in the report including explanation of the compelling reason that prompted the modification.
2. The mitigation report shall contain a summary of the repair procedures, which typically includes a summary of observations made during the repair, comparison of the anticipated anomaly volumes with the actual grout quantities used, and the results of testing if performed.

Table 1 – Grout Mix Table						
Mix	Cement (bags)*	Water (gallon)	Weight (lbs)	Volume (gallons)	Density (lbs/gal)	W/C
1	1.0	33.0	319.2	34.9	9.1	6.3
2	2.0	33.0	363.2	36.8	9.9	3.1
3	3.0	33.0	407.2	38.8	10.5	2.1
4	4.0	33.0	451.2	40.7	11.1	1.6
5	5.0	33.0	495.2	42.6	11.6	1.3
6	6.0	33.0	539.2	44.2	12.2	1.0
7	7.0	33.0	583.2	46.0	12.7	0.9
8	8.0	33.0	627.2	48.0	13.1	0.8

Note: * Based on 22 kg (48.4 lb) per bag.